OPERATING INSTRUCTIONS

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TYPES 1610-B AND -B2

CAPACITANCE MEASURING ASSEMBLY

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GENERAL RADIO COMPANY

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OPERATING INSTRUCTIONS

TYPES 1610-B AND -B2

CAPACITANCE MEASURING ASSEMBLY

Form 1610-0100-E
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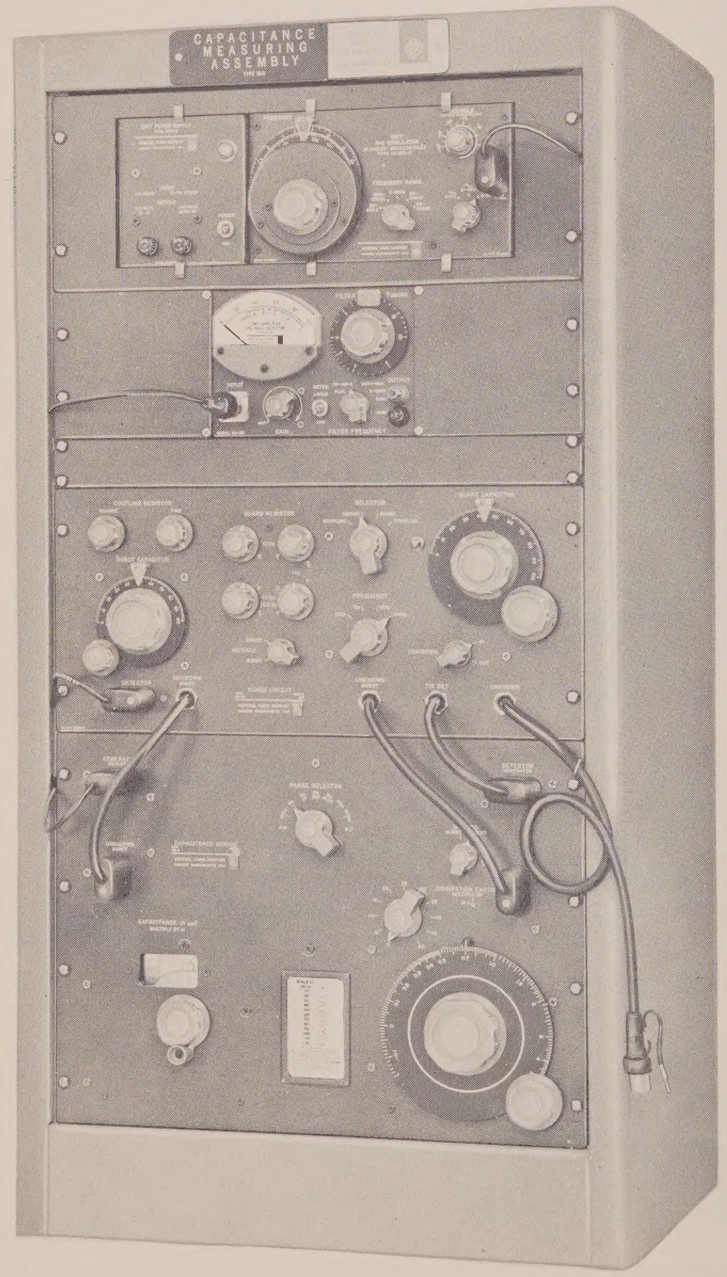


Figure 1.
The Type 1610-B Capacitance Measuring Assembly.

TYPE 1610-B AND -B2

CAPACITANCE MEASURING ASSEMBLY

NOTE. The Type 1610-B2 Capacitance Measuring Assembly is similar to the Type 1610-B Capacitance Measuring Assembly, but does not include the Type 716-P4 Guard Circuit, for three-terminal measurements. Throughout this book, reference to the Guard Circuit will apply only to the Type 1610-B Assembly.

Section 1
INTRODUCTION

1.1 PURPOSE. The Type 1610 Capacitance Measuring Assembly is a general-purpose capacitance bridge combined, in an integrated assembly, with the necessary generator, detector, and interconnecting cables. A guard circuit is also included in the Type 1610-B for certain specialized measurements. Either assembly measures equivalent series capacitance from zero to 1150 μμf and dissipation factor over a frequency range from 30 cps to 100 kc. In the vicinity of 1 kc, the capacitance range extends to 1 μf. In addition to its use in capacitance measurements, the Capacitance Measuring Assembly finds wide application in evaluating the dielectric properties of insulating materials, not only for electrical applications but also in the fields of chemical and biological research and as a production control tool.

1.2 DESCRIPTION. The Type 1610-B Capacitance Measuring Assembly consists of the following instruments, relay-rack mounted and suitably interconnected:

a. The Type 716-C Capacitance Bridge, a Schering bridge which is direct reading in capacitance from 30 cps to 300 kc, and in dissipation factor at 100 cps, and 1, 10, and 100 kc.

b. The Type 716-P4 Guard Circuit, which permits three-terminal measurements to be made.

c. The Type 1210-C Unit Oscillator with a frequency range of 20 cps to 500 kc, with output from a cathode-follower-type amplifier.

d. The Type 1203-B Unit Power Supply, to provide plate and heater power to the Type 1210-C Unit R-C Oscillator.

e. The Type 1232-A Tuned Amplifier and Null Detector, a sensitive, fully transistorized null detector which tunes continuously over the frequency range from 20 cps to 20 kc, with spot coverage at 50 kc and 100 kc.

1.3 ACCESSORIES. For measurements of dielectric properties of solid insulating materials, the Type 1690-A Dielectric Sample Holder is available. Provision is made for mounting this instrument directly onto the panel of the Type 716-C Capacitance Bridge.

Section 2
INSTALLATION

2.1 INITIAL ASSEMBLY.

2.1.1 TYPE 1610-B. After placing the connecting cables in the correct rack notches, mount the instruments as shown in Figure 1. By starting the assembly at the bottom, each unit helps to support the one above. The oscillator panel requires a 1/16"-thick washer, and the amplifier a 1/8" spacer under each mounting screw to make all panel faces level. The bridge GENERATOR (DETECTOR) terminals connect to the oscillator output terminals with the Type 0274-2080 Cable via the lower notch on the left and top notch on the right sides of the rack. The guard circuit DETECTOR terminals connect to the amplifier INPUT terminals with the Type 0874-2590 Cable via the upper two notches on the left side of the rack. The narrow blank panel is mounted between the guard circuit and the detector so that the rubber feet need not be removed from the latter. The power supply cord plugs into the outlet at the bottom rear of the rack.

2.1.2 TYPE 1610-B2. The procedure for this assembly is the same as for the Type 1610-B. In order, from bottom to top, are installed bridge, amplifier, oscillator and wide blank panel. The bridge GENERATOR terminals connect to the oscillator output terminals with the Type 0274-2080 Cable via the lower notches on the left and right of the rack. The bridge DETECTOR terminals connect to the amplifier with the Type 874-256 Cable across the front of the panels.

NOTE

BE SURE THAT ALL SHIELDED PLUGS ARE ORIENTED SO THAT THE GROUND SIDE (IDENTIFIED BY A METAL SCREW ON THE CASE) IS CONNECTED TO THE GROUNDED TERMINAL OF THE INSTRUMENT.

2.2 PRELIMINARY CONNECTIONS FOR TWO-TERMINAL MEASUREMENTS. For best sensitivity the guard circuit should be bypassed by a direct connection between amplifier INPUT and capacitance bridge DETECTOR terminals. Adequate sensitivity for most measurements will be obtained by connecting the bridge to the detector through the guard circuit (see paragraph 2.3) with both COUPLING RESISTOR controls at maximum (fully clockwise).

2.3 PRELIMINARY CONNECTIONS FOR THREE-TERMINAL MEASUREMENTS, DIRECT METHOD. Connect the guard circuit cables designated as UNKNOWN SUBST. and UNKNOWN DIRECT to the corresponding terminals on the panel of the Type 716-C Capacitance Bridge. The cable marked 716 DET is connected to the DETECTOR terminals of the bridge. The remaining cable, labeled UNKNOWN, provides means for connection to the component under measurement.

2.4 PRELIMINARY OPERATING TESTS. The following preliminary checks are recommended to ensure that the equipment is functioning properly. If unfamiliar with this general type of apparatus, read the Operating Instructions for the individual instrument and Sections 3, 4, and 5 of this manual before attempting any capacitance measurements.

2.4.1 TESTS WITH GUARD CIRCUIT DISCONNECTED.

2.4.1.1 OSCILLATOR. Turn on the Type 1210-C Oscillator by means of the switch on the Type 1203-B Power Supply. Select any appropriate frequency, such as 1 kc. Set the the output switch to 0-45 V. Advance the DECIBELS control and increase the setting toward 0. With a suitable means of detection (headphones or Type 1232-A Tuned Amplifier and Null Detector) connected to the output terminals of the oscillator, note the presence of output.

2.4.1.2 AMPLIFIER AND FILTER SETTINGS. Turn on the Type 1232-A Amplifier by means of the GAIN control and advance the control until a meter indication is obtained. Vary the GAIN control of the amplifier and the OUTPUT control of the oscillator to be sure that the meter reading varies. Adjust the filter to the same frequency as that supplied by the oscillator by means of the FILTER FREQUENCY switch and the FILTER TUNING dial. Note the meter reading on the null indicator. Change the switch position of the filter to other frequency settings and note a decrease (counterclockwise) in meter indication.

2.4.1.3 BRIDGE BALANCE. Using the procedures outlined in Paragraph 4.5, make a trial balance using a capacitor of known approximate value.

2.4.2 TESTS WITH THE GUARD CIRCUIT CONNECTED. Complete familiarity with the bridge and associated equipment should be acquired before measurements with the guard circuit are attempted. A reading of the Type 716-P4 Guard Circuit Operating Instructions is recommended.

The following procedure will afford practice in three-terminal-measurement technique and will also determine whether the guard circuit is functioning properly:

a. Measure, by the two-terminal method, the exact value of a mica capacitor whose marked value is about 500 μμf.

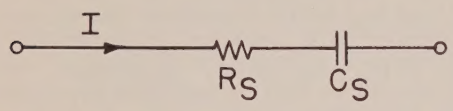
b. Connect this capacitor with two others (also about 500 μμf) to form a three-terminal network (see Figure 4a).

c. Prepare the measuring assembly for three-terminal measurements. Connect the three-terminal network to the UNKNOWN cable in the following manner: cable high (inner Type 874) connection to one side of the capacitor measured in step "a," cable ground connection (lead) to the other side. The guard connection (outer Type 874) is made to the junction of the other two capacitors (see Figure 6).

d. Following the procedures outlined in Section 4.2, obtain a balance. If the guard circuit is functioning, the measured value should agree with the value obtained by the two-terminal method.

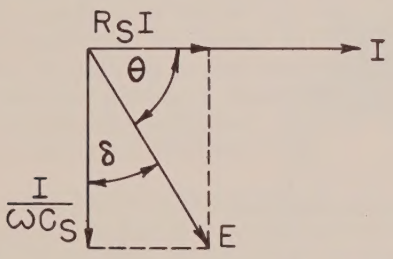
Section 3
PRINCIPLES OF OPERATION

3.1 CHARACTERISTICS OF CAPACITORS. Every capacitor is characterized by a loss parameter as well as the desired capacitance parameter. The loss parameter can be represented as either a series or a parallel resistance. The series notation, as measured by the Type 716-C Capacitance Bridge, is:



where C_S is the pure capacitive component and R_S is the series resistance or loss component.

The vector diagram for the series equivalent is:

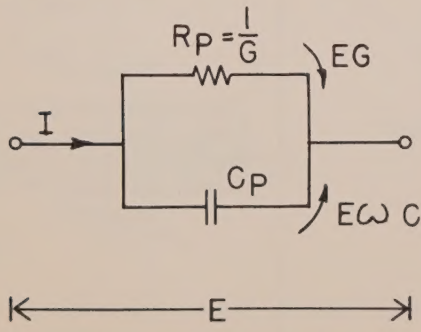


where Θ is the phase angle and δ is the dielectric-loss angle.

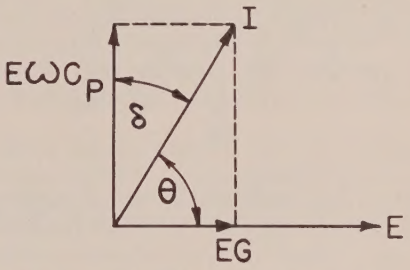
In the series equivalent case the dissipation factor, D, defined as the cotangent of the dielectric phase angle, is:

$$D = \text{Cot}\,\Theta = \tan\delta = \frac{R_S}{\frac{1}{\omega C_S}} = \omega C_S R_S \qquad (1)$$

In parallel notation the equivalent circuit is:



where the resistance, R_p, represents the loss component, G is the conductance, and the capacitance, C_p, is the pure capacitive component. The vector diagram for the equivalent parallel circuit may be represented as:



where again Θ is the phase angle and δ is the dielectric-loss angle.

Then, the dissipation factor, D, is:

$$D = \text{Cot}\,\Theta = \tan\delta = \frac{G}{\omega C_p} = \frac{1}{\omega C_p R_p} \qquad (2)$$

The series equivalent and parallel equivalent values can be related to one another by the following equations and are essentially equal when D is small.

$$C_p = \frac{C_s}{1 + D^2} = \frac{C_s}{1 + \tan^2\delta} = C_s \cos^2\delta \qquad (3)$$

$$R_p = \frac{R_s (1 + D^2)}{D^2} = \frac{1 + D^2}{D\omega C_s} \qquad (4)$$

3.2 MEASUREMENTS OF DIELECTRIC MATERIALS. The dielectric constant and dissipation factor of insulating material are measured by placing the material to be tested between electrodes to form a capacitor. The capacitance and dissipation factor of the dielectric are then determined by normal bridge techniques. From this measured value, the dielectric constant of the material can readily be found. For a full mathematical treatment and discussion on the evaluation of dielectric constants and loss factors refer to the American Society for Testing Materials Specification D-150.

3.3 TYPE 716-C CAPACITANCE BRIDGE. The Type 716-C Capacitance Bridge is a modified Scher-ing bridge, whose simplified schematic is shown in Figure 2.

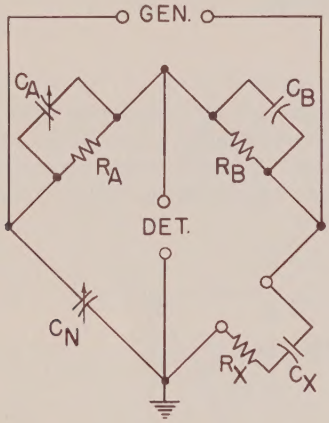


Figure 2. Simplified Circuit Diagram of Type 716-C Capacitance Bridge (DIRECT).

The capacitor C_N is a precision, worm-driven unit, adjusted to be direct-reading in capacitance. The direct-reading range is 100 to 1150 μμf, given as the sum of the drum and dial readings.

The dissipation factor controls consist of a variable air capacitor and a decade capacitor, which are represented in the simplified diagram as C_A. These are calibrated to be direct reading in dissipation factor of the unknown at the frequency selected by the RANGE SELECTOR.

The RANGE SELECTOR controls the ratio arms R_A and R_B, which determine the multiplier ratio M. Equal ratio arms are provided for 100 cps, 1 kc, 10 kc, and 100 kc. In addition, multiplying factors, M, of 10, 100, and 1000 are provided at 1 kc.

Figure 3 is a pictorial representation showing the bridge controls, their placement in the simplified circuit, and the generator and detector.

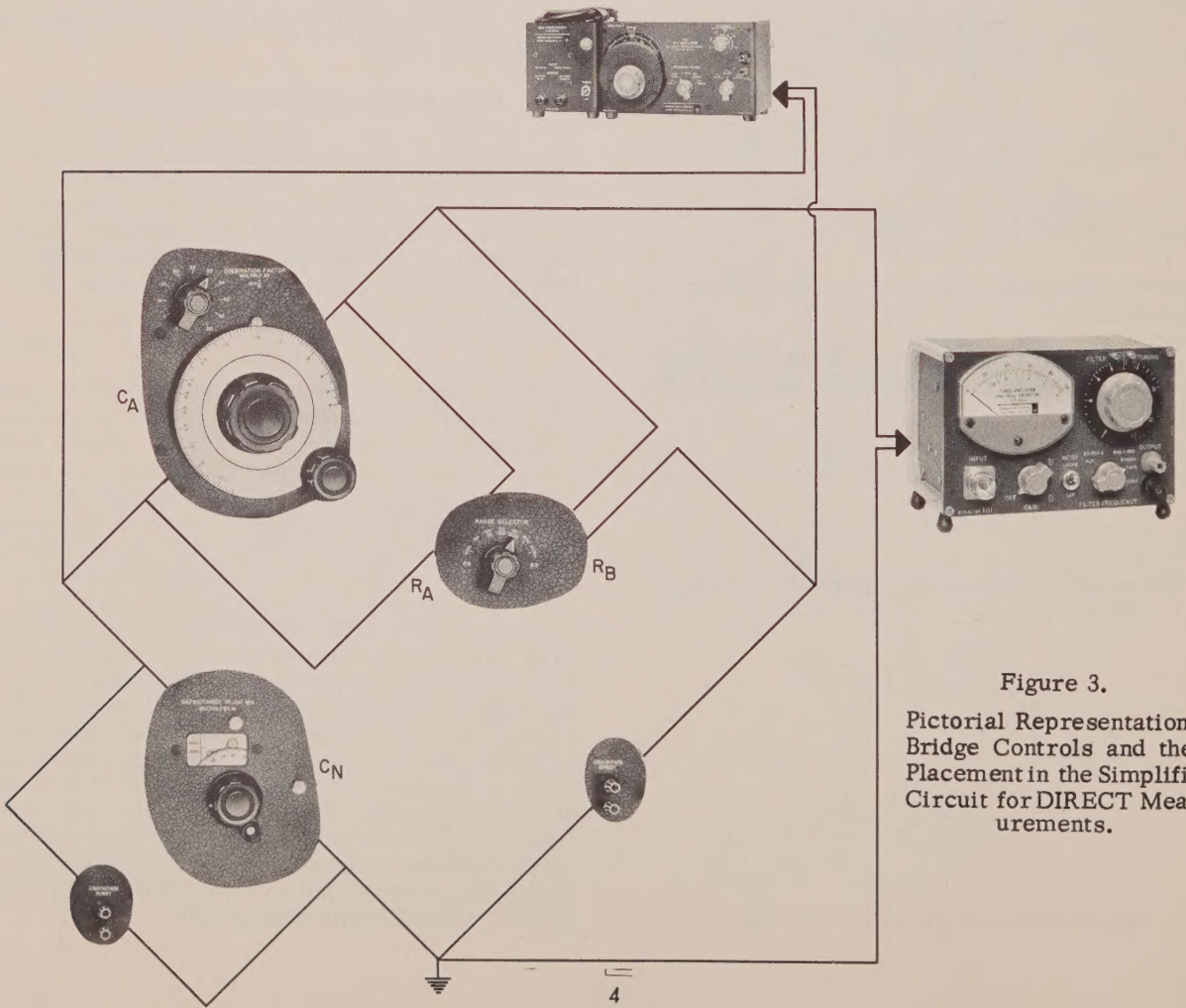


Figure 3.

Pictorial Representation of Bridge Controls and their Placement in the Simplified Circuit for DIRECT Measurements.

The equations of balance for the Schering bridge circuit are:

$$C_x = C_N \frac{R_A}{R_B} \quad (5)$$

$$D_x = R_A \omega C_A \quad (6)$$

where C_x is the series equivalent capacitance of the unknown, and D_x is the dissipation factor of the unknown.

3.4 TYPE 716-P4 GUARD CIRCUIT. It is frequently desirable to measure the direct capacitance between two points, each of which has capacitance or complex impedance to a third point, as suggested by Figure 4a. Such a configuration is sometimes produced deliberately, as, for example, when a "guard ring" (see Figure 4b) is introduced in an electrode system used for the measurement of dielectric materials, either liquid or solid. In other cases it arises inevitably, as, for instance, in a variable air capacitor in which both rotor and stator are insulated from the frame. In this instance, there exists, in addition to the desired direct capacitance between plates, a capacitance between each plate structure and frame. Another common example is a two-wire shielded cable.

The Type 716-P4 Guard Circuit provides a means of measuring the direct capacitance between two specified electrodes, eliminating from the measurement the capacitance from each of these electrodes to the third electrode, which is connected to the guard point. Figure 5 shows schematically the combination of guard circuit and bridge.

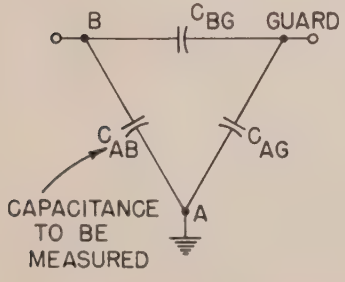


Figure 4a.

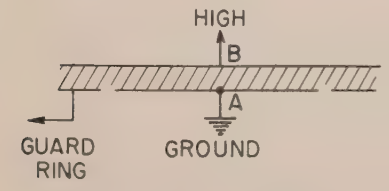


Figure 4b.

Configuration of a Three-Terminal Capacitor

By proper adjustment of the resistance-capacitance combination S, the guard point can be brought to the same potential as the detector terminals of the bridge. When this condition is realized, the bridge reads correctly the capacitance and dissipation factor connected in the UNKNOWN arm.

Figure 6 is a pictorial representation of the controls of the guard circuit, superimposed on the schematic diagram.

The Type 716-P4 Guard Circuit also provides a means for making accurate measurements of a capacitor or a dielectric sample located at some distance from the measuring terminals of the bridge. Measurements of materials or components in a conditioning chamber or oven, while exposed to a specified temperature or humidity, may thus be made.

When measurements are to be made by the substitution method, it is necessary to connect a balancing capacitor in the adjacent arm of the bridge. A variable air capacitor (SUBST. CAPACITOR), with a maximum capacitance of 1150 μμf, is built into the guard circuit for this purpose, and is connected across the UNKNOWN DIRECT terminals when the guard METHOD switch is in the SUBST. position.

3.5 TYPE 1690-A DIELECTRIC SAMPLE HOLDER. Although not an integral part of the Type 1610-B Measuring Assembly, the Type 1690-A Dielectric Sample Holder is often used in conjunction with it, for measuring the dielectric properties of solid materials.

The accepted method of evaluating the dielectric constant and dissipation factor of a solid dielectric material is to place the material between metallic electrodes and to measure the capacitance and dissipation factor of the resulting capacitor. One of the simplest electrode systems is a pair of circular plates; the Type 1690-A Dielectric Sample

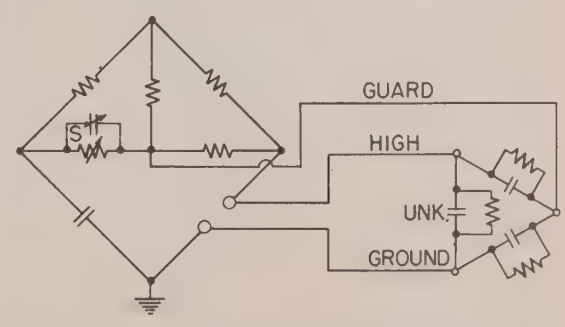


Figure 5. Simplified Diagram of the Type 716-P4 Guard Circuit and Type 716-C CAPACITANCE BRIDGE (DIRECT).

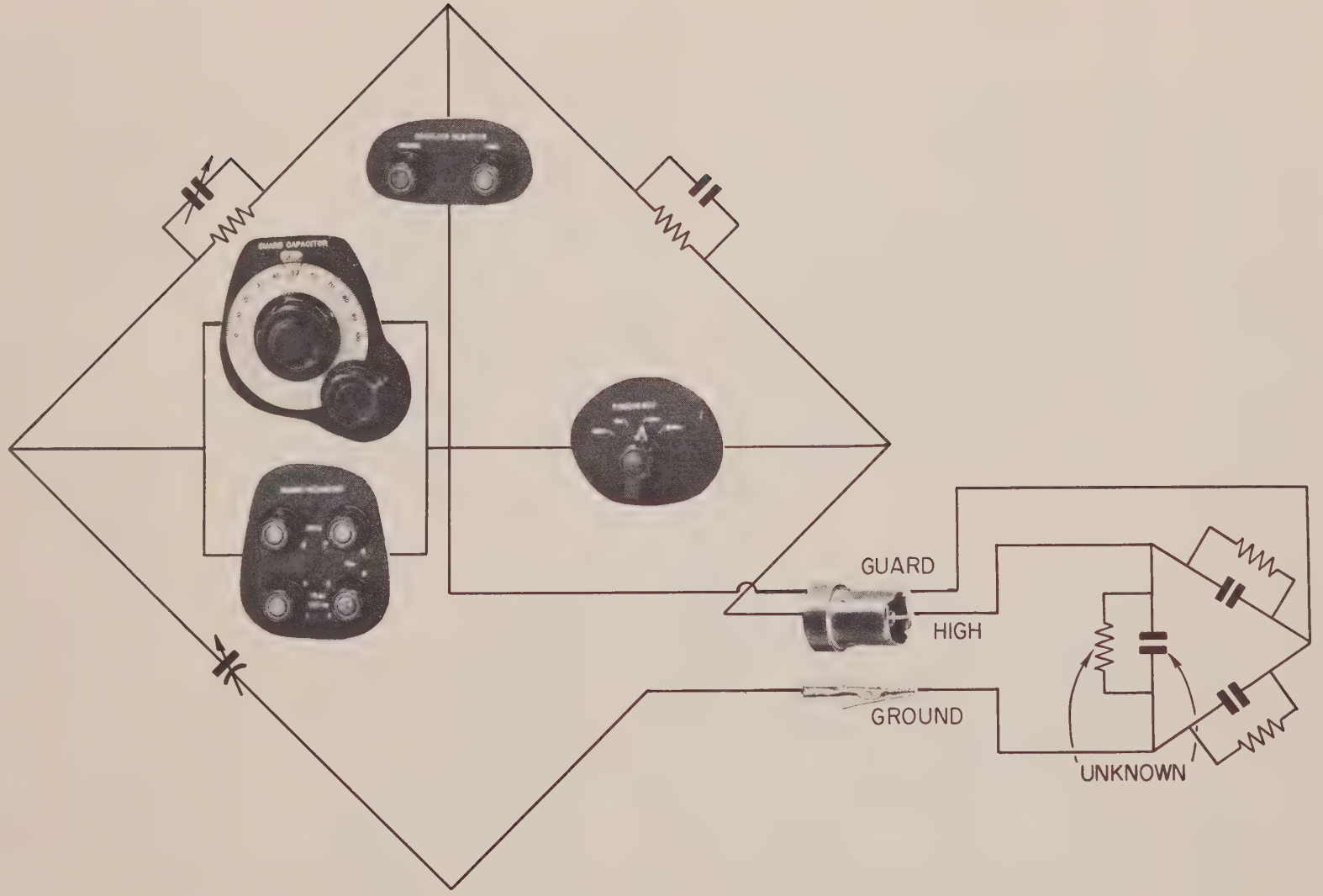


Figure 6.
Pictorial Representation of the Guard Circuit Controls and their Placement in the Simplified Circuit for DIRECT Measurement.

Holder is basically such an arrangement (see Figure 7).

The micrometer-capacitor type of holder has been recognized as the most satisfactory method of holding specimens of solid dielectric material for measurement at radio frequencies. Holders of this type are recognized in ASTM Specification D-150 for use in the frequency range to about 100 Mc. In addition, the use of this type holder, properly calibrated, virtually eliminates the errors from fringing fields and stray capacitance. For this reason its use at lower frequencies is also recommended.

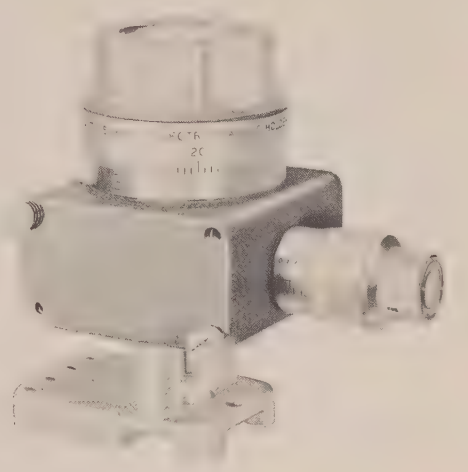


Figure 7. Type 1690-A Dielectric Sample Holder with the Type 1690-P1 Adaptor.

Section 4

OPERATING PROCEDURE

4.1 GENERAL. The Capacitance Measuring Assembly can be used in four different ways for the measurement of capacitance. The choice depends on whether the capacitor to be measured is two- or three-terminal, and on the accuracy requirement.

The four methods are:

A. Direct-Reading Measurement with the Guard Circuit.
B. Substitution Measurement with the Guard Circuit.
C. Direct-Reading Measurement less Guard Circuit.
D. Substitution Measurement less Guard Circuit.

Method A is used with three-terminal capacitors, guarded dielectric specimens, and when components or dielectric materials are measured at a distance from the bridge terminals, with a guarded cable used to eliminate lead capacitance from the measurement.

Method B is used under the same conditions as method A, but will yield greater accuracy.

Method C is the most rapid and convenient method. It is used for two-terminal measurements of components and of dielectric samples when a guard electrode is not used.

Method D is used for the same measurements as method C, but yields higher accuracy of measurement, particularly for values of dissipation factor that are less than 0.0001.

In the following sections step-by-step procedures for each method are given.

4.2 PROCEDURE FOR THREE-TERMINAL OR GUARDED-NETWORK MEASUREMENTS USING THE DIRECT METHOD.

Capacitance range: 100 to 1150 μμf
Frequency range: 30 cps to 300 kc
Accuracy: capacitance, ±0.1% ±1 μμf when dissipation factor of unknown is less than 0.01; dissipation factor, ±0.0005 or ±2% of dial reading, whichever is the larger, for values of D below 0.1 This accuracy can be maintained when D is greater than these limits by using the equations given in the Type 716-C Operating Instructions.

Connect the assembly as outlined in paragraph 2.3. Connect the component under measurement to the unknown cable. The three connections on the unknown cable are: the "high" connection, which is the center conductor of the Type 874 Connector, the guard connection, which is the outer shell of the connector, and the "ground" connection, which is the pigtail lead (see Figures 6 and 8). The capacitor under measurement is connected between "high" and "ground."

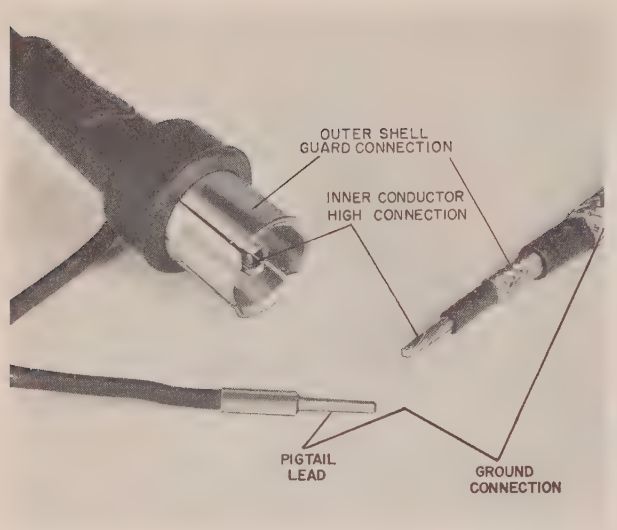


Figure 8.
Guarded Cable Connection.

a. Turn on the oscillator by means of the POWER switch on the Type 1203-B Unit Power Supply.

b. Type 1210-C Unit R-C Oscillator.

(1) Set the output switch at 0-45 V and the output control at a low value, such as -40 DECIBELS.

(2) Set the FREQUENCY RANGE switch and the FREQUENCY dial at the desired frequency.

c. Type 1232-A Tuned Amplifier and Null Detector (Amplifier).

(1) Turn on by advancing the GAIN control slightly from the OFF position.

(2) Set the METER switch at the LOG position.

(3) Power Supply: 12 volts dc, from 9 mercury (M 72) cells in series, under the cover at the right end of the case.

d. Type 1232-A Tuned Amplifier and Null Detector (Filter).

(1) Set the FILTER FREQUENCY switch at the desired range.

(2) Adjust the FILTER TUNING dial to the frequency of the oscillator, as indicated by maximum meter deflection.

(3) The 50 kc and 100 kc positions on the FILTER FREQUENCY switch connect fixed band-pass filters. When these frequencies are used the Type 1210-C Oscillator FREQUENCY dial should be adjusted for maximum amplifier-meter deflection.

(4) A band-pass filter may be plugged into EXTERNAL FILTER jack at the right end of the case, for any frequency not covered by the built-in filter.

Balance:

e. Set the following on the Type 716-P4 Guard Circuit:

(1) METHOD switch to DIRECT position.

(2) UNKNOWN switch to IN.

(3) FREQUENCY switch to the nearest value of frequency as produced by the Type 1210-C Unit R-C Oscillator.*

(4) SELECTOR switch to BRIDGE position.

f. Set the following on the Type 716-C Capacitance Bridge:

(1) METHOD switch to DIRECT position.

(2) RANGE SELECTOR switch to the nearest value of frequency produced by the Type 1210-C Oscillator. Note that the Guard Circuit is not intended to operate at the M10, M100 or M1000 positions. The bridge will operate at all frequencies from 30 cps to 300 kilocycles with the accuracies stated, provided that the ratio of the frequency f applied to the bridge to the frequency f_0 indicated by the RANGE SELECTOR switch lies between 0.1 and 3. No correction for f/f_0 is necessary for capacitance between these limits. The correction for dissipation factor, however, is directly proportional to frequency. (See equation engraved on Capacitance Bridge panel.)

g. Adjust both CAPACITANCE IN μμf and DISSIPATION FACTOR controls alternately for a minimum meter reading on the Type 1232-A Tuned Amplifier and Null Detector. If necessary, advance the GAIN and/or DECIBELS controls. Headphones connected to the OUTPUT terminals of the Type 1232-A Amplifier can be used in the vicinity of one kilocycle, if desired.

h. Make the following adjustments on the Type 716-P4 Guard Circuit:

(1) Set the SELECTOR switch to the GUARD position.

(2) Adjust the GUARD CAPACITOR for a minimum meter reading on the Type 1232-A Amplifier.

(3) Beneath the area marked GUARD RESISTOR four knob controls are grouped together. Select the pair that function at the frequency set on the FREQUENCY switch. This is indicated on the panel by engraving between the knobs. The letters "C" and "F" indicate coarse and fine adjustments. Care should be taken in determining which "C" or "F" belongs to which frequency (see Figure 9). Should adjustment on the fine control be lacking, return the fine control to its center position and readjust the coarse control for minimum meter reading.

(4) Turn the SELECTOR switch to either COUPLING position.

(5) Adjust the COUPLING RESISTOR for a minimum meter reading. Here again, coarse and fine adjustments are provided. A precise balance is not normally needed, but a partial coupling balance facilitates the bridge and guard circuit balances.

* Set to next higher frequency for capacitors with high

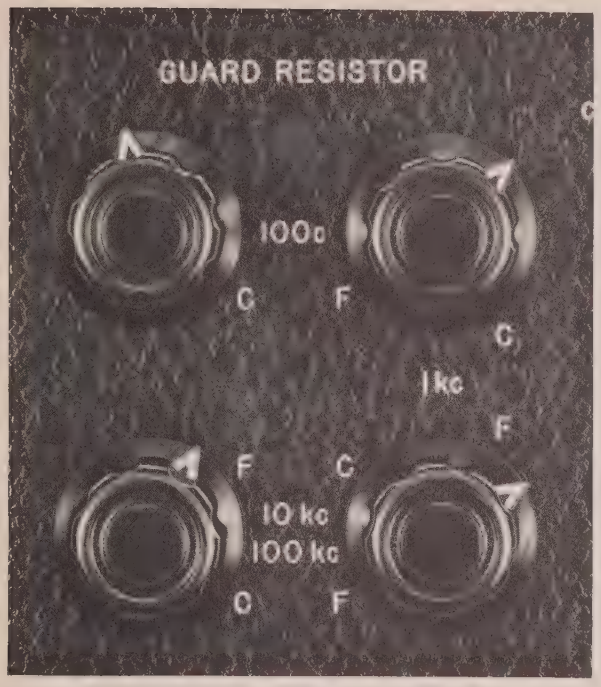


Figure 9. Panel Arrangement of Guard Resistor Controls. For example: at 100 kc the bottom left-hand control is the coarse adjustment and the bottom right-hand control is the fine adjustment.

(6) Return the SELECTOR switch to the BRIDGE position.

Final Balance:

i. Repeat the procedure in paragraphs 4.2g and 4.2h until readjustments of the CAPACITANCE in μμf and DISSIPATION FACTOR settings are unnecessary. To obtain additional sensitivity for bridge balance, advance the DECIBELS control of the Type 1210-C Oscillator and/or the GAIN control of the Type 1232-A Tuned Amplifier and Null Detector.

j. The value of series capacitance in μμf is then read directly on the CAPACITANCE IN μμf drum and dial (since M=1) and the value of dissipation factor is found from the equation:

$$D_x = 0.01 \frac{f}{f_o} D \qquad (7)$$

where:

D = sum of the readings of the DISSIPATION FACTOR switch and dial setting.
f = frequency setting of the oscillator.
f_o = frequency setting of the bridge RANGE SELECTOR.

Additional equations in terms of parallel and series equivalent values will be found in the Type 716-C Operating Instructions.

4.3 PROCEDURE FOR THREE - TERMINAL OR GUARDED - NETWORK MEASUREMENTS USING THE SUBSTITUTION METHOD.

Capacitance range: 0.1 to 1050 μμf
Frequency range: 30 cycles to 300 kc
Accuracy: capacitance, ±0.2% or ±1.2 μμf, whichever is the larger; dissipation factor, ±0.00005 or ±2% of the change in dissipation factor observed, when the change is less than 0.06. Using the correction chart, measurements can be made to ±0.03% or ±0.6 μμf, whichever is the larger. For capacitances less than 25 μμf the error will decrease linearly to ±0.1 μμf. With a precision calibration (supplied at extra charge), substitution measurements can be made to an accuracy of ±0.03% or ±0.2 μμf, whichever is the larger.

Follow the preliminary procedure outlined in steps 4.2a through 4.2d of the Procedure for Direct Method Measurements.

a. Set the following on the Type 716-P4 Guard Circuit:

METHOD switch to SUBST,
UNKNOWN switch to IN.
FREQUENCY switch to nearest frequency as produced by the Type 1210-C Oscillator, and
SELECTOR switch to BRIDGE.

b. Set the following on the Type 716-C Capacitance Bridge:

METHOD switch to SUBST,
CAPACITANCE IN μμf to a convenient low value, such as 100 μμf,
RANGE SELECTOR switch to nearest frequency as produced by the Type 1210-C Oscillator. Note that the Guard Circuit is not intended to operate with the bridge RANGE SELECTOR at M10, M100, or M1000.

c. Adjust the SUBST CAPACITOR in the Guard Circuit alternately with the DISSIPATION FACTOR switch and dial controls on the bridge to obtain a minimum meter reading.

d. Follow the procedure outlined in step 4.2h in the Procedure for Direct Method Measurements.

e. Repeat steps 4.3c and 4.3d until further readjustment is unnecessary.

f. Record the settings of the CAPACITANCE IN μμf and DISSIPATION FACTOR controls. Note that the dissipation factor is the sum of the switch setting plus the dial reading.

g. Set the following switches in the Guard Circuit:

UNKNOWN switch to OUT, and
SELECTOR switch to BRIDGE.
DO NOT DISTURB SUBST CAPACITOR SETTING.

h. Repeat steps 4.2g, 4.2h, and 4.2i in the Procedure for Direct Method Measurements.

i. When the unknown capacitor has a dissipation factor less than 0.1, its capacitance and dissipation factor can be calculated from the changes in readings of the CAPACITANCE and DISSIPATION FACTOR dials.

$$C_x = \Delta C \qquad \Delta C = C' - C \tag{8}$$

$$D_x = \frac{C'}{\Delta C}(\Delta D) \qquad \Delta D = (D - D')\,0.01 \times \frac{f}{f_0}$$

where readings with the unknown disconnected (UNKNOWN switch in OUT position) are designated by primes and Δ signifies "change in". C and D are bridge readings with the unknown connected (UNKNOWN switch in IN position), f is the frequency setting of the oscillator, and f_0 is the frequency setting of the bridge RANGE SELECTOR switch.

These equations will be accurate when the calculated dissipation factor is found to be less than 0.1, and approximately correct for values greater than 0.1.

When the calculated dissipation factor is found to be greater than 0.1, the complete equations in the Type 716-C Capacitance Bridge Operating Instructions will give accurate results. These equations will give results in terms of parallel or series equivalent values.

4.4 GUARDED MEASUREMENTS OF TWO-TERMINAL NETWORKS. Use of the guard circuit in two-terminal measurements is advantageous when it is desired to eliminate the capacitance of leads connecting the unknown to the bridge. Such a condition occurs when the component under test is a considerable distance away from the bridge. If guarded cable, such as "triaxial" cable (see Figure 8) is used in connecting the component under test to the bridge, the lead capacitance can be balanced out. The component under measurement is connected as shown in Figure 6 (but with GUARD disconnected) to the UNKNOWN cable of the guard circuit, extended as necessary. The cable shield then effectively becomes the guard point of a three-terminal network. This double-shielded cable (Type ESMW-16) can be purchased from the General Radio Company.

The procedure for measurement is the same as the methods for three-terminal guarded measurements.

4.5 TWO-TERMINAL DIRECT MEASUREMENTS WITHOUT GUARD CIRCUIT.

Capacitance range: 100 μμf to 1 μf at 1 kc; 100 μμf to 1150 μμf at 100 cps, 10 kc, and 100 kc.
Frequency range: 30 cps to 300 kc.

Prepare the assembly for measurement as outlined in paragraph 2.2. Connect the component under test to the UNKNOWN DIRECT terminals on the bridge panel. Follow steps 4.2a to 4.2d, 4.2g, and 4.2j in the procedure for three-terminal direct measurements using the guard circuit.

4.6 TWO-TERMINAL SUBSTITUTION MEASUREMENTS WITHOUT GUARD CIRCUIT.

Capacitance range: 0.1 μμf to 1050 μμf with the internal standard; to 1 μf with external standards. For measurements above 1050 μμf, refer to the Type 716-C Capacitance Bridge Operating Instructions.
Frequency range: 30 cps to 300 kc.

Prepare the assembly for measurement as outlined in paragraph 2.2. Follow steps 4.2a to 4.2d in the procedure for three-terminal direct measurements using the guard circuit.

a. Set the following on the Type 716-C Capacitance Bridge:

(1) METHOD SWITCH to SUBST.

(2) RANGE SELECTOR switch to the frequency position nearest to that used, and to a capacitance position for M equals 1.

(3) Connect a balancing capacitor to the UNKNOWN DIRECT terminals. This balancing capacitor must be at least 100 μμf larger than the unknown capacitor and may be either fixed or variable.

(4) Connect the low terminal of the unknown capacitor to the UNKNOWN SUBST terminal marked G. Leave the lead from the remaining UNKNOWN SUBST terminal disconnected at the high terminal of the unknown capacitor and separated from it by about 1/4 inch. Make these leads of stiff, small-diameter wire. (If unknown has plugs, leave disconnected.)

(5) Balance the bridge for capacitance and dissipation factor as described in step 4.2g in the procedure for three-terminal direct measurements with the guard circuit. Record these values of C' and D'.

(6) Connect the high lead to the high terminal of the unknown capacitor and rebalance the bridge. The new reading for capacitance will be less than, and the new reading for dissipation factor will be greater than, the initial readings. (Plug in unknown.)

(7) Refer to step 4.3i in the procedure for three-terminal substitution measurements with guard circuit for calculation of capacitance and dissipation factor. (For plug-equipped unknowns, this method gives the insertion capacitance when plugged into General Radio binding posts.)

Section 5

PRECAUTIONS AND SPECIAL CONSIDERATIONS

5.1 GENERAL. In this section are included discussions of several aspects of the use and operation of this equipment. These are intended for the chemist, the biologist, the physicist, and others who are not familiar with the precision measurements of capacitance and related parameters.

5.2 GROUNDING. It is important, particularly when measurements are made at or near 60 cps, that the equipment be solidly connected to a good ground. If this precaution is not observed, hum voltages may be induced in the system, which will obscure the balance point or introduce actual error in the measurement. With proper grounding, it should be possible for the operator to touch the cabinet, the instrument panels, or the bridge controls, without significant effect on the bridge balance.

Also, in a properly grounded and otherwise properly functioning system it should be possible to reverse the power plug without altering the balance point. A change in reading with power reversal may also be the result of electrostatic pickup (paragraph 5.3) or magnetic pickup (paragraph 5.4).

It is essential, of course, that the cables interconnecting the various instruments of the assembly be properly connected. All these cables are shielded and correct orientation of the shielded plugs is necessary to ground the shields. The ground side of these plugs is identified by a "G" cast in the metal case and/or the mounting screw.

5.3 ELECTROSTATIC SHIELDING. In any laboratory or industrial location, 60-cycle electrostatic fields of considerable magnitude may exist. When a high-impedance (to ground) circuit is exposed to such fields, a 60-cycle voltage will be induced in that circuit. The magnitude of the induced voltage depends on the capacitance between the exposed circuit element and the source of interference. This capacitance in turn depends on the physical size of the exposed portion of the circuit. For this reason, 60-cycle pickup trouble is often encountered in the measurement of large capacitors, or in the measurement of dielectric materials when a large unshielded electrode is used.

The measuring equipment and its interconnecting leads are, of course, carefully shielded. Care must be taken that the unknown capacitor and its connecting leads are sufficiently shielded against interference.

When the measuring frequency is other than 60 cps, the discrimination available in the filter of the Type 1232-A Tuned Amplifier and Null Detector greatly reduces the interference. Pickup should be kept to a reasonable minimum, even in these cases, since the presence of the undesired voltage can in some instances alter the apparent characteristics of the capacitor being measured. In the event of severe pickup, overloading of the first stages of the detector may occur.

5.4 MAGNETIC INTERFERENCE. In some locations, strong magnetic fields may be a source of trouble. The input transformer of the bridge is magnetically shielded, but it is impractical to shield the entire equipment against magnetic fields. The circuits are relatively immune to magnetic pickup but when very precise measurements are being made, fluctuating fields, such as may result from the operation of nearby switches, transformers, motors, etc., may cause trouble. Line-voltage regulators of the saturable-core type are sometimes offenders, as are autotransformers if in close proximity to the bridge.

5.5 LINE-VOLTAGE FLUCTUATIONS. Although the oscillator and detector are both provided with electronically regulated power supplies, severe line-voltage transients may cause fluctuation of the meter near balance. If such trouble occurs, an effort should be made to provide a power line to which no heavy, intermittent loads are connected. Welding equipment, for instance, is likely to be a source of trouble.

5.6 BRIDGE VOLTAGE. The bridge voltage may be increased to 500 volts from 60 cps to 1 kc, 190 volts at 10 kc, and 60 volts at 100 kc if the generator and detector connections are reversed. Connect the detector to the bridge GENERATOR terminals and connect an external generator to the guard-circuit DETECTOR terminals using a 2-watt, 200 Ω/volt protective resistor. If the guard circuit is not used, the generator can be connected directly to the bridge DETECTOR terminals (a protective resistor is not needed).

5.7 SENSITIVITY CONSIDERATIONS. The overall sensitivity of balance, or resolution, of the measuring system depends upon three factors: the voltage impressed by the signal source upon the bridge, an intrinsic bridge sensitivity factor, and the sensitivity of the detector system employed to detect the bridge unbalance voltage. The voltage on the

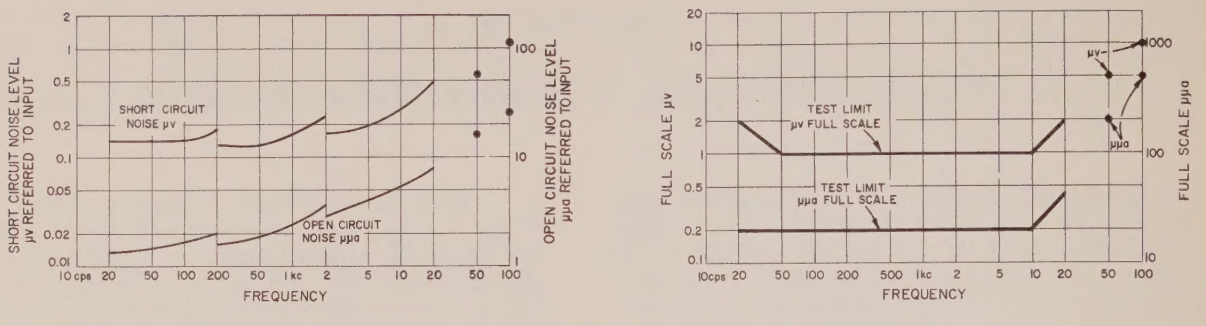


Figure 10.
Sensitivity of the Type 1232-A Tuned Amplifier and Null Detector.

bridge in turn depends upon the available open-circuit voltage, the output impedance of the oscillator, and the input impedance of the bridge. The bridge sensitivity factor can be computed from the constants of the bridge circuit. For the Type 716-C Capacitance Bridge the expression is:

$$S = \frac{E\ out}{E\ in} = \frac{M\,d}{(1 + M)^2} \qquad (9)$$

where M is the multiplier and d is the fractional unbalance, in capacitance or dissipation factor.

The output voltage E_{out} resulting from an unbalance as given by this expression is the open-circuit voltage of the bridge network. The actual voltage appearing at the detector input terminals depends on the impedance connected across the detector terminals of the bridge, and on the output impedance of the bridge circuit.

The maximum voltage impressed on the bridge by the Type 1210-C Unit R-C Oscillator varies from 5 volts to 13 volts, depending upon the frequency and the RANGE SELECTOR setting, with the oscillator output switch at 0-45 V (open circuit).

The sensitivity factor S, as given by equation (9) is 1/4, 1/12, 1/100, 1/1000 for multiplier settings of 1, 10, 100, and 1000, respectively. Note that this factor is independent of f_o.

The output voltage appearing across the DETECTOR terminals of the bridge is less than the open-circuit voltage calculated from equation (9) due to the shunting effect of the internal capacitance to ground from the detector junction and the capacitance of the cable connecting to the null detector. This total capacitance is approximately 700 μμf. The reduction in available voltage resulting from this shunt capacitance is significant only for the M = 1 multiplier positions. The output impedance of the bridge is essentially the parallel combination of the unknown and standard capacitance. Thus, in the extreme case of M = 1, and with a measured capacitance of 100 μμf, the output capacitance is 200 μμf and the available output voltage is about 1/5th of that calculated from equation (9).

The 1-megohm input impedance (at maximum gain) of the Type 1232-A Tuned Amplifier and Null Detector is sufficiently high so that no loss in voltage occurs except at very low frequencies.

The relative sensitivity of the Type 1232-A Tuned Amplifier and Null Detector as a function of frequency is shown in Figure 10.

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